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Abstract

Watershed runoff is closely related to land use, but this influence is difficult to quantify. This study focused on the Chaudière River watershed (Québec, Canada) and had two objectives: (i) to quantify the influence of historical agricultural land use evolution on watershed runoff; and (ii) to assess the effect of future land use evolution scenarios under climate change conditions (CC). To achieve this, we used the integrated modeling system GIBSI. Past land use evolution was constructed using satellite images that were integrated into GIBSI. The general trend was an increase of agricultural land in the 1980s, a slight decrease in the beginning of the 1990s and a steady state over the last ten years. Simulations based on thirty years of daily meteorological series showed strong correlations between land use evolution and water discharge at the watershed outlet, especially for summer and fall seasons. For the prospective approach, we first assessed the effect of CC and then defined two opposite land use evolution scenarios for the horizon 2025 based on two different trends: agriculture intensification or sustainable development. Simulation results showed that CC would induce an increase of water discharge during winter and a decrease the rest of the year, while land use scenarios would have a more drastic effect, agriculture intensification counterbalancing the effect of CC during summer and fall. Due to the large uncertainty linked to CC simulations, it is difficult to conclude that one land use scenario provides a better adaptation to CC than another, but this study shows that land use is a key factor that has to be taken into account when predicting potential future hydrological responses of a watershed.

1 Introduction

River hydrology and water quality is influenced by many natural and anthropogenic factors that occur at the watershed scale. It is well known that land use constitutes one of these factors, and that deforestation of one piece of land for agricultural or urban

HESSD

4, 1337–1367, 2007

purpose can affect locally water balance and pollutant fate. This influence of land use is difficult to quantify, especially over the long term and at a large scale such as the watershed scale where complex interactions occur. Recent developments of decision support systems based on a geographic information system (GIS) and a distributed hydrological model have provided practical and useful tools to achieve this goal (Fohrer et al., 2001). All the studies based on such models show that deforestation for agricultural land or urbanisation induces an increase in water discharge and peak flow, but with various intensities. For instance, Costa et al. (2003) showed that increase of agricultural land from 30% to 49% of the Tocatins River watershed (Brazil, 767 000 km^2) led to a 24% increase of the mean annual water discharge. On the other hand, Fohrer et al. (2001) found only a moderate effect of land use change scenarios on the annual water balance of the small Dietzhölze watershed (Germany, 82 km^2). Moreover, Dunn and MacKay (1995) showed, using the distributed SHETRAN model, that land use change has more influence on lowland subwatersheds than on highland subwatersheds. Thus, the intensity of the effect of land use on water regime depends on the size, the slope and land use characteristics of the watershed (see also Cognard-Plancq et al., 2001; Matheussen et al., 2000). Obviously, it also depends on the hydrological model used and the physical processes simulated. Note that it is also possible to use these models to define an optimal land use change that would enable to achieve a specific objective such as reducing peak flow or nonpoint source pollution (Yeo et al., 2004).

Assessment of land use effect on hydrology is of special interest regarding the expected climate changes (CC). Indeed, most of the studies that have tried to forecast the effect of CC on hydrology and water quality consider that the watershed configuration would stay the same in the future as today (for instance Wood and Maurer, 2002). However, it is likely that land use will continue to evolve over the next decades, notably as an adaptation to CC and to regional and world economies, and that it will have an important influence on future watershed hydrology (Kite, 1993; Pielke, 2005).

In this study, we used the integrated modeling system GIBSI (see description below) to assess the effect of agricultural land use on the hydrology and soil erosion of the

Chaudière River watershed (Québec, Canada), both under past and future conditions. Indeed, it is important to understand what happened in the past before trying to assess what would be the role and influence of both CC and land use evolution on future watershed hydrology (Crooks and Davies, 2001). Note that GIBSI has already been used to assess the effect of clear cutting on watershed hydrology (Lavigne et al., 2004) leading to consistent results. The first part of this study consists in determining the land use changes over the Chaudière River watershed between years 1970 and 2003 using remote sensing. The resulting land use maps will be compared and finally introduced in the geographic database of GIBSI to assess the impact of land use evolution on hydrological regime. Then, the second part of the study focuses on defining land use evolution scenarios and simulating their influence on hydrology and soil erosion under future climatic conditions.

2 GIBSI

GIBSI is an integrated modelling system designed to assist stakeholders in decision making process for water management at the watershed scale (Rousseau et al., 2000; Villeneuve et al., 1998). It is basically composed of a MySQL® database management server, a GIS and a graphical user interface (GUI). The modeling part is based on the semi-distributed hydrological model HYDROTEL (Fortin et al., 2001a). The hydrological model is sensitive to land use configuration by the mean of the Manning coefficient (for generation of surface runoff), leaf area index and root depth (for actual evapotranspiration calculation). The erosion model of GIBSI is based on RUSLE (Renard et al., 1997; Wischmeier and Smith, 1978) which has been complemented by Yalin's equation (Yalin, 1963) to account for sediment transport capacity and the sediment routing model of SWWRB (Arnold and Williams, 1995). Other models can be used (i.e. nitrogen, phosphorus and pathogens transport), but they were not considered in this study. All models run on a daily time step with meteorological data (precipitation, minimum and maximum temperature) as inputs. Outputs are daily streamflow and water qual-

HESSD
4, 1337–1367, 2007

EGU

ity data at any computational segment of the river network. Pre- and post-processing tools enable to easily define management scenarios, run simulations and analyse the results. The 1995 land use configuration is used by default in the database and for simulations. It was determined based on a satellite image processed and validated with 1994 survey data (Villeneuve et al., 1998).

3 The Chaudière River watershed

The Chaudière River watershed is located south of Quebec City and covers an area of 6682 km^2 (Fig. 1). It was selected because it is representative of many watersheds of the Saint-Lawrence River valley, with various land uses: 63% forest, 17% agricultural land, 15% bush, 3% urban development and 2% surface water. Soils vary from loam in the upper part of the watershed to clay loam in the middle part and loamy sand in the lower part. Agriculture is dominated by animal production, especially pig and dairy farming. This implies that most of farmed lands are forages and pasture (75% of agricultural land in 1995). The population of the watershed is around 180 000 inhabitants. For the application of GIBSI, the study watershed was subdivided into 1870 elementary basins or spatial simulation units (SSUs, with a mean area of 3.6±1.9 km^2), 10 lakes (5.6±8.3 km^2), 1799 river segments (1.9±1.2 km), and 46 lake segments (1.5 km±4.4 km). Calibration of the hydrological model HYDROTEL was performed on the whole watershed (Fortin et al., 2001b) considering measured and simulated streamflows at the outlet. A first calibration of the erosion model was also performed in 2002 (unpublished). Note that improvements and further calibration of this model are in progress. Several management-oriented applications of GIBSI on the Chaudière River watershed have been performed over the last ten years and are described by Quilbé et al. (2007).

4 Data and methods

4.1 Effect of historical land use evolution

4.1.1 Past land use evolution reconstruction

This part is described in details by Savary et al. (2007)[1]. Identification of land use evolution was based on seven Landsat satellite images acquired over the 1965–2004 period (Table 1). Their selection was based on several criteria such as the period of the year (summer period is better for crop identification) and watershed cover. The image processing methodology includes three steps: pre-processing, classification and analysis. Pre-processing operations are essential for exploiting satellite products and allowing the analyst to work within a geo-referenced environment and to restore image quality. They include radiometric and geometric transformations, as well as image resizing for the watershed area. Classification started with the identification of clouds and water classes using mask application. Then, a supervised object-oriented classification was performed using eCognition (Definens Imaging, 2001) which considers not only pixel spectral characteristics but also forms, textures and neighbourhood notions. As field land use knowledge was not available, training site definition was mainly supported by visual image interpretation and previous works on the Chaudière River watershed (Dolbec et al., 2005; Gauthier, 1996). Finally, correction of unclassified regions (clouds) was made using the nearest date class availability. The resulted land use classes are presented in Table 2.

[1]Savary, S., Rousseau, A. N., and Quilbé, R.: Assessing the impact of past land use changes on runoff and low flows using remote sensing and distributed hydrological modeling – a case study for the Chaudire River watershed (Quebec, Canada), Hydrol. Processes, submitted, 2007.

4.1.2 Effect on hydrology and erosion

The classified images were integrated into GIBSI by automatic modification of the land use tables of the database. Simulations were run with measured meteorological sequences over 30 years (1970–1999). Each year was simulated independently. Results include daily streamflow and sediment concentration series at any computational segment of the river network of the Chaudière River watershed. We checked the effect at the watershed outlet as it integrates the effect of both land use evolution and climate change over the whole watershed.

4.2 Effect of future land use evolution

This prospective approach had to take into account not only potential evolution of land use in a near future, but also the evolution of climate. The time interval considered in this study is 30 years, the reference period being from 1970 to 1999 and the future period from 2010 to 2039. The choice of a short term prediction implies that modeled changes in watershed hydrology will be slight but avoids a too important uncertainty in climate change and especially agricultural evolution prediction. As stated by Butcher (1999), it is impossible to develop realistic land use projections for a period of more than 20 to 30 years. The general approach is depicted on Fig. 2.

4.2.1 Determination of future meteorological series

The meteorological variables that have to be determined for the future period are the input variables of the semi-distributed hydrological model HYDROTEL which are daily minimum temperature (TMIN), maximum temperature (TMAX) and precipitation (P). Several methods exist, the most popular being the use of General Circulation Models (GCMs) based on greenhouse gas emission scenarios (GES). GCMs accurately predict climatic variables such as wind and temperature at a large scale. However, hydrology depends on meteorological variables such as precipitation, minimum and maximum temperatures or evapotranspiration, at the land surface level and at a fine spatial and temporal scale (Xu, 1999). To fill this gap and determine future local meteorological sequences from GCM output, we used two methods: (1) delta (or incremental) method and (2) statistical downscaling (SD). Note that a third method combining the delta method with the downscaled data was also used for comparison purposes, but results will not be presented here (see Quilbé et al., 2007[2]). For the delta method, several GCMs and GESs were available. We selected the three GCMs that gave the best results as compared to measured data over the reference period: (i) the third version of the Coupled General Circulation Model (CGCM3) from the Canadian Centre for Climate Modelling and Analysis – this version is based on CGCM2 (Flato et al., 2000) and incorporates a new version of the atmospheric component as described by Scinocca and McFarlane (2004); (ii) the third version of the Hadley Centre for Climate Prediction and Research model HadCM3 (Johns et al., 2001); and (iii) the Max Planck Institute for Meteorology model ECHAM4 (Roeckner et al., 1996). Several GESs can be considered for each GCM, as reported in the Special Report on Emission Scenarios (SRES). Basically, scenarios family A2 and scenarios family B2 correspond to pessimistic and optimistic GES, respectively. For each scenario family, several simulation members (M) are available and characterized by different initial conditions (for instance A2-a and A2-b). We selected the GESs-M combinations that gave the largest range of future meteorological conditions (see Table 3). For the SD method, the only available GCM was HadCM3, based on two GESs (see Table 3). The SD procedure was performed with SDSM (Wilby et al., 2002) for nine meteorological stations out of the 40 available stations. More details about methods and results are given by Quilbé et al. (2007)[2].

[2]Quilbé, R., Rousseau, A. N., Moquet, J.-S., Dibike, Y. B., and Gachon, P.: Assessing the effect of climate change on river flow using general circulation models and hydrological modelling. Application to the Chaudière River (Québec, Canada), J. Can. Water Resour. J., submitted, 2007.

4.2.2 Land use evolution scenarios

The base case scenario regarding land use was the 1995 configuration. Then, two opposite scenarios of future land use evolution were defined to represent a wide range of possible configurations.

1. Scenario A is based on the assumption that pig production will remain the priority incentive of agricultural development in the region. Thus, the evolution of pig production over the last 30 years is extrapolated to the next 20 years, from 89 739 animal units in 1995 to 136 370 animal units in 2025 (1 animal unit corresponds to 30.3 pigs). As a consequence of this increase, land use has to be adjusted. Indeed, increased pig production implies conversion of more agricultural land for pig food production (that is grain corn) and manure spreading, to the detriment of cereals, pasture, shrub land and forest areas. Four land use classes were found to be correlated with pig production over the past 30 years: corn, pasture, forest and cereals. Then, the future class areas were extrapolated based on regression curves and future pig production.

2. Scenario B is based on the assumption that agriculture will make a radical change and come back to the land use configuration of 1976, with reforestation to the detriment of shrub land and pasture. This scenario also considers a spatial dispersion of corn and cereal lands over the whole watershed.

For both scenarios, the shrub land class is used as a buffer class to implement deforestation or reforestation. For scenario A, we make the assumption that, as most of these lands were farmed in the 1970s, they are the most likely to be farmed again. Thus, new corn fields replaced shrub land, and then forest area when there is no more shrub land. For scenario B, we considered that these lands will naturally transform into young forests. Note that urban area is considered to stay the same as today.

These changes were integrated into GIBSI using the land use management GUI. One limitation of this system is that, for a given spatial management unit (watershed, subwatershed, municipality or SSU), every change in land use is done by a complete transfer of one class to another. Therefore, we made a calculated number of transfers on different SSUs (for example all forest transformed into shrub land on one SSU, and all pasture transformed into corn on another SSU) so that the overall proportions are respected at the watershed scale. The corresponding land use distributions are depicted on Fig. 3.

Note that this procedure presents some subjectivity, especially in the case of scenario A. However, what is important is the general tendency at the watershed scale and the results should be considered as possible tendencies with respect to present conditions and not be interpreted in a quantitative way.

4.2.3 Effect on hydrology and erosion

GIBSI simulations were performed with original meteorological sequences and with modified (i.e. future) sequences, over 30 years. As for the retrospective approach, each year was simulated independently. Regarding water quantity, comparisons between present and future are made with respect to mean annual, seasonal and monthly water discharge. In order to see the effect of climate change and land use evolution on low-flow events, a frequency analysis was performed using HYFRAN© software (Chaire en hydrologie statistique, 2002). We determined critical streamflow sequences over seven and thirty consecutive days. These are Q_{2-7}, Q_{10-7} and Q_{5-30} corresponding to return periods of respectively two, ten and five years. We also considered the spring peak flow. Finally, the annual and seasonal sediment loads were compared. It should be noted that, by using the models under climate change conditions, we may not be in the calibration domain any more. Thus, we made the assumption that the calibration parameter set remains optimal (Drogue et al., 2004).

HESSD

4, 1337–1367, 2007

Title Page
Abstract | Introduction
Conclusions | References
Tables | Figures
◀| |▶
◀ ▶
Back | Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

EGU

5 Results

5.1 Effect of historical land use evolution

Figure 4 presents the temporal evolution of land use over the Chaudière River watershed. We can see that agricultural land class is characterised by fluctuations attributed to the cereals class variability, while pasture area is steadier. These fluctuations of agricultural land are inversely correlated to forest evolution. This is due to the fact that new agricultural lands are mostly taken from shrub lands (shrub is included in the forest class), while shrub replaces agricultural lands when neglected. The mean annual runoff, simulated with GIBSI and based on 30-year meteorological series, was also found to be strongly correlated with agricultural land (r^2=0.97), with a minimum of 492 mm for the 1981 land use configuration and a maximum of 555 mm for the 1990 land use configuration (see Fig. 5), and a coefficient of variation (c_v) of 4.6%. Note also that the effect of land use on water discharge is statistically significant (p<0.001, Friedmann test). It should also be noted that this effect of agricultural land on annual runoff is homogeneous over the thirty years of simulations, meaning that the relative effect is stronger for dry years. It is also important to note that this effect is more important from June to November, while there is no effect in winter and spring. Indeed, in the latter period, runoff occurs mostly under saturated soil conditions, since evapotranspiration is then negligible it means that the kind of vegetation (i.e. crop vs. forest) does not influence water balance. Besides, the mean spring peak flow, although correlated to land use, does not vary a lot (minimum of 1309 m^3/s with 1981 land use configuration, maximum of 1337 m^3/s with 1999 land use configuration, c_v=0.8%, p<0.001). On the other hand, in summer and fall, runoff is due to rainfall events, thus dense vegetation cover such as forest makes a big difference as compared to farmed land. For these reasons, good correlations were also found between agricultural land and summer low flow sequences as obtained with the frequency analysis, with determination coefficients of 0.95, 0.93 and 0.93, respectively, for Q_{2-7}, Q_{10-7} and Q_{5-30}. These results confirm that the hydrological regime of the Chaudière River watershed is highly sensitive to land use. We also used GIBSI to investigate the effect of land use evolution on erosion. The annual sediment load was found to vary much more than annual runoff (c_v=67.5%, p<0.001) but to be less correlated with agricultural land area (r^2=0.75). We can see on Fig. 5 that, the evolution of these two variables is slightly different in some periods. Indeed, runoff increases from 1976 to 1981 while sediment load decreases, and the opposite occurs from 1995 to 1999.

5.2 Effect of future land use evolution under climate change

5.2.1 Effect of climate change

First, we assessed the effect of future CC on water discharge and erosion, the other factors being equal, i.e. considering that no change occurs in land use (i.e., 1995 configuration, that is the reference land use). The results of simulations obtained with the future meteorological sequences are compared to those performed with the meteorological sequences for the reference period (measured data for delta method or simulated data for SD). Figure 6 shows the annual water discharge obtained with the Delta method (delta) over the thirty years of simulation. We can see an important dispersion depending on the GCM-GES-M combination used. If we assume all GCM-GES-M combinations as equiprobable, the mean trend is a slight decrease of annual discharge (mean of −2.7%) which is statistically significant (p<0.01 with a paired t-test). Actually, water discharge would increase in winter and decrease during the rest of the year (Fig. 7). This is in all likelihood due to the higher temperatures predicted by GCMs in winter that induce less snow, more rain, and an earlier snowmelt, and more evapotranspiration during summer. This effect on water discharge also implies an effect on erosion as simulated with GIBSI with a mean of −12.5% (p<0.001). The GCM-GES-M combinations that induce an increase in water discharge also induce an increase in annual sediment load and inversely (not shown). However, it is interesting to note that the absolute effect (increase or decrease depending on GCM-GES-M) on sediment load is not homogeneous over the thirty years of simulation: it is stronger on wet years than on dry years. Meanwhile, the effect on water discharge is homogeneous (Fig. 6). This means that the main effect of CC would more specifically concern water discharge during dry years and erosion during wet years. Regarding daily streamflow, results obtained with SD method are probably more reliable than those from delta method as the former accounts for a change in precipitation frequency and intensity while the latter does not. Unfortunately, only one GCM (HadCM3) could be considered. The results show a decrease in spring peakflow for HadCM3-A2a (−3.8% for the mean over the thirty years, not significant) and for HadCM3-B2a (−12.9%, $p<0.05$). Finally, regarding summer low flows, results are heterogeneous. The HadCM3-A2a combination induces a strong increase of Q_{2-7} but a decrease of Q_{5-30} and Q_{10-30}, while HadCM3-B2a induces an increase of all sequences. Note that results regarding water discharge are discussed in details in Quilbé et al. (2007)[2].

5.2.2 Effects of land use evolution scenarios

The previous results only account for the effect of CC without any change in watershed configuration. The next step was to simulate the effect of the two land use evolution scenarios under these CC conditions. Regarding the delta method, we consider here only the two GCM-GES-M combinations that give the extreme effect on water discharge, i.e. ECHAM4-B2 and HadCM3-A2b (see Fig. 4), as they represent the whole range of possible future conditions. The results are depicted on Fig. 8 and show that, in both cases, Scenario A would induce an important increase of water discharge from May to November, while Scenario B would induce a slight decrease over the same period. Regarding annual runoff, the mean effect would be +13.6% ($p<0.001$) and −7.2% ($p<0.001$), respectively, for Scenarios A and B (considering the two GCM-GES-M as equiprobable). Since the mean effect of CC would be a slight decrease of annual runoff, these results mean that an intensification of agriculture (Scenario A) would mitigate and even counterbalance the effect of CC while a scenario B would intensify this effect. As shown in the first part of this study, these results are due to the strong correlation between agricultural land area and water discharge. As Scenario A includes an increase of agricultural land to the detriment of shrub land and forest, this implies an increase of runoff over the watershed in spring and fall. It is the opposite effect for Scenario B. The same effect was found regarding low flow sequences with the SD method, with an increase for Scenario A and a decrease for Scenario B. We can see on Fig. 9 that the fact to consider land use scenarios A and B induces a stronger effect on low flow sequences than when considering only CC without any land use change (1995 land use configuration). Note that these results are obtained from only one GCM and that other GCMs may lead to a different pattern. Regarding erosion, the mean annual sediment load was found to increase with Scenario A (+11.7%, $p<0.001$, considering the two GCM-GES-M as equiprobable) and decrease with Scenario B (−4.8%, $p<0.001$). This follows the water discharge trend.

It is important to keep in mind that important uncertainty and many assumptions are linked to the methodological approach that was used to determine the future meteorological sequences (see Quilbé et al., 2007[2]). For instance, the use of different methods (delta versus statistical downscaling) and different data sets (i.e. GCM-GES-M combinations) led to a wide range of results, some of them being contradictory. Moreover, the intensity of extreme meteorological events are not well predicted by those methods, even statistical downscaling (Gachon et al., 2005), so that the effect on peak flow and low flow are also tainted with uncertainty. Also, the hydrological model calibration was performed for a specific time period and land use configuration, and we have to make the assumption that the resulting calibration parameter set remains optimal under different climate and land use conditions. Finally, important factors are not taken into account by this approach, such as potential implementation of irrigation. Consequently, it is difficult to conclude that one land use evolution scenario would be better than another under CC conditions. Bouraoui et al. (1998) performed the same kind of approach with the ANSWERS model to assess the expected effects of long term CC (doubling of CO_2) and land use management scenarios on the water balance, particularly drainage below the crop root zone. They showed that CC will induce a decrease of groundwater recharge and that this effect will be much smaller with alternative techniques such as winter wheat and/or alfalfa. Thus, in this case, sustainable agriculture would mitigate the effect of CC. Moreover, this kind of interpretation should first consider what is desirable regarding water uses, which is a water management issue. In this regard, the effect of CC and land use scenarios on pollutant loads and water quality has also to be considered as it was shown that some land use changes drastically affect many water quality parameters (Tong and Chen, 2002; Wilby et al., 2006).

Further work should use more confident techniques such as dynamical downscaling based on Regional Climate Models, to predict the effect of CC in a more reliable way. However, a major problem rising in such studies is that, on one hand, the assessment of CC effect on hydrology has to consider a long term trend (at least 2050 horizon) to produce an effect that is strong enough to be clearly related to CC and not to GCMs output variability, while on the other hand, realistic land use evolution scenarios can only be determined at short term (Butcher, 1999).

6 Conclusion

The first part of this study clearly shows the strong effect that land use, and especially agricultural land use, had on the hydrological regime of the Chaudière River watershed between 1970 and 1999. Therefore, as illustrated in the second part of this study, it is of major importance to take into account possible future land use evolution when forecasting the behaviour of a watershed within a CC context. Yet, due to the uncertainty linked to the prediction of CC effect, it is difficult to conclude about the mitigation effect of the two opposite land use scenarios considered in this study. However, they induce much stronger effects than CC on the water regime and sediment load of the Chaudière River, confirming that land use will be a key factor in adaptation to CC.

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Table 1. Satellite images used for the caracterisation of land use evolution on the Chaudière River watershed.

Acquisition date	Satellite and sensor
4 Sep 1976	Landsat-2 MSS
14 Sep 1981	Landsat-2 MSS
6 Sep 1987	Landsat-5 TM
29 July 1990	Landsat-5 TM
28 Aug 1995	Landsat-5 TM
14 July 1999	Landsat-7 ETM+
2 Sep 2003	Landsat-5 TM

Table 2. Land use classes used in GIBSI.

Class number	Land Use classes
1	Urban
2	Pasture
3	Cereals
4	Corn
5	Water
6	Wetland
7	Bare Soil
8	Shrub land
9	Deciduous Forest
10	Evergreen Forest

HESSD

4, 1337–1367, 2007

Influence of historical and future land use on watershed hydrology

R. Quilbé et al.

EGU

Table 3. GCM-GES-M combinations used with the two methods for determining future meteorological series.

GCM	GES	Member	Delta	SD
CGCM3	A2	1	x	–
	B1	3	x	–
HadCM3	A2	a	x	x
		b	x	–
	B2	a	x	x
		b	–	–
ECHAM4	A2	–	x	–
	B2	–	x	–

HESSD

4, 1337–1367, 2007

Influence of historical and future land use on watershed hydrology

R. Quilbé et al.

EGU

Fig. 1. The Chaudière River watershed.

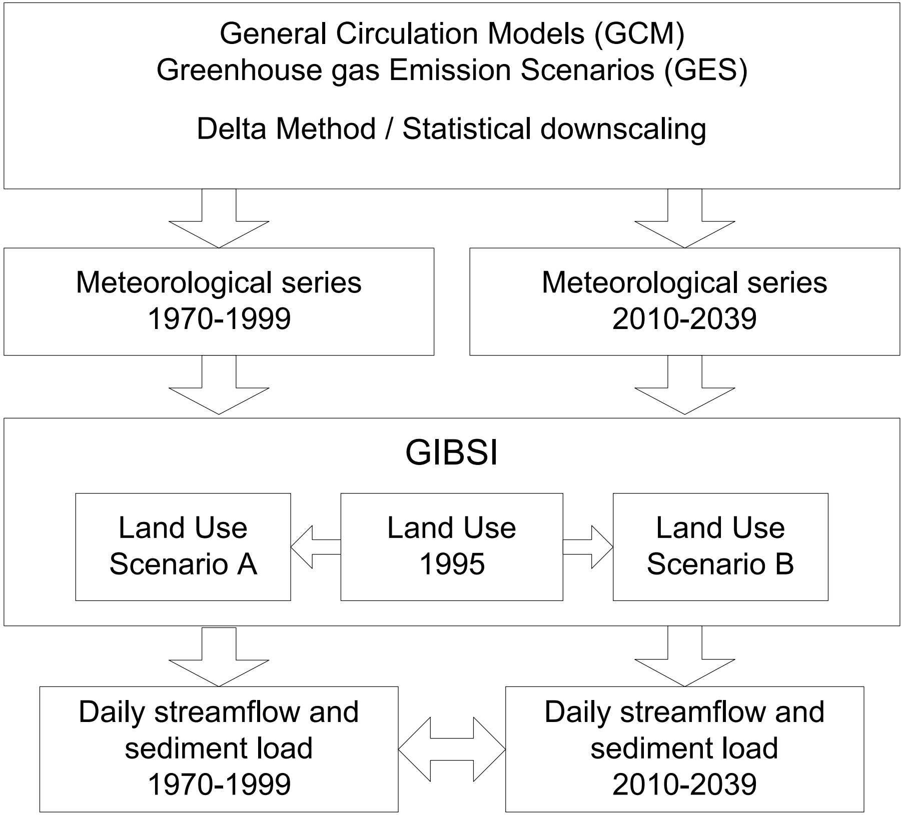

Fig. 2. General approach used to assess the effect of CC and land use evolution scenarios on hydrology.

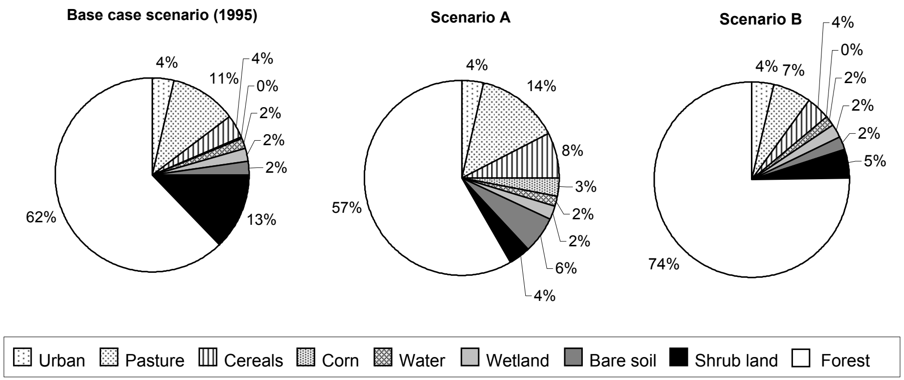

Fig. 3. Repartition of land use on the watershed for base case scenario, Scenario A and Scenario B.

HESSD

4, 1337–1367, 2007

Influence of historical and future land use on watershed hydrology

R. Quilbé et al.

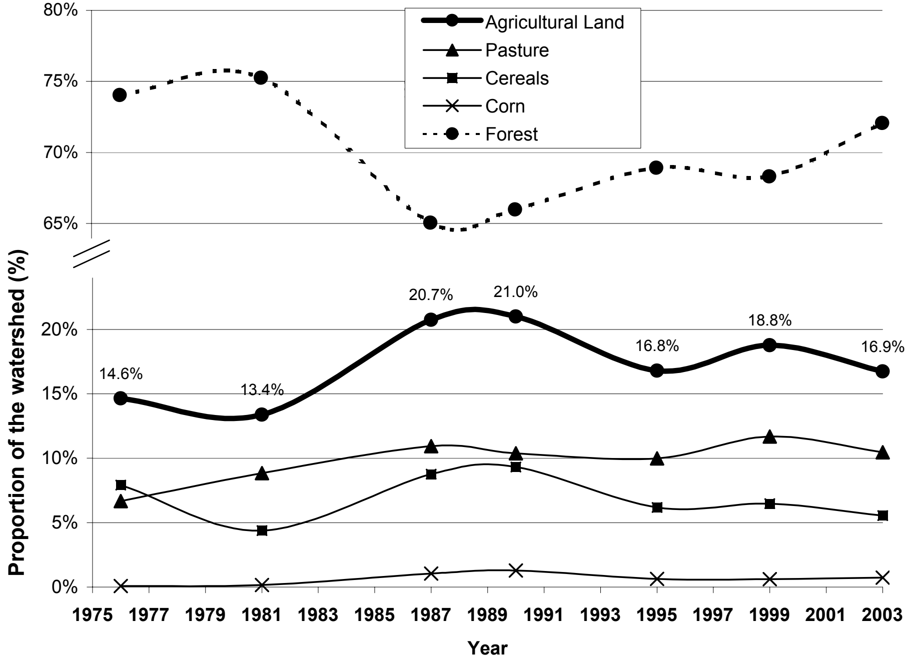

Fig. 4. Evolution of agricultural and forest land use on the Chaudière River watershed over the past 30 years.

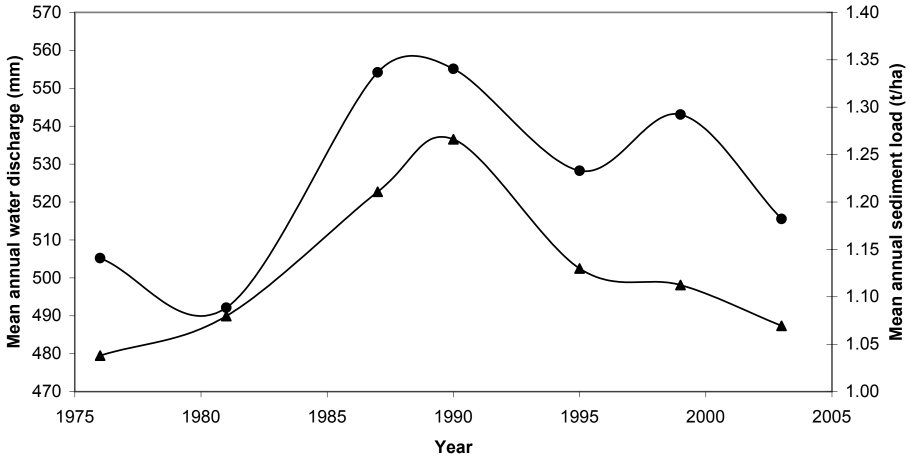

Fig. 5. Evolution of the mean annual water discharge (circles) and the mean annual sediment load (triangles) at the outlet of the Chaudière River watershed simulated with GIBSI as a function of land use configuration.

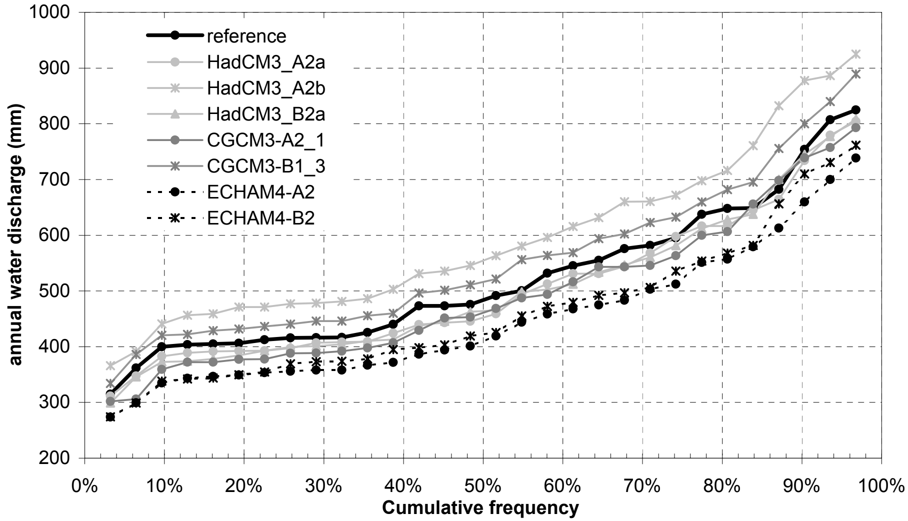

Fig. 6. Effect of CC on annual water discharge at the outlet of the Chaudière River watershed using the delta method and several GCM-GES-M combinations.

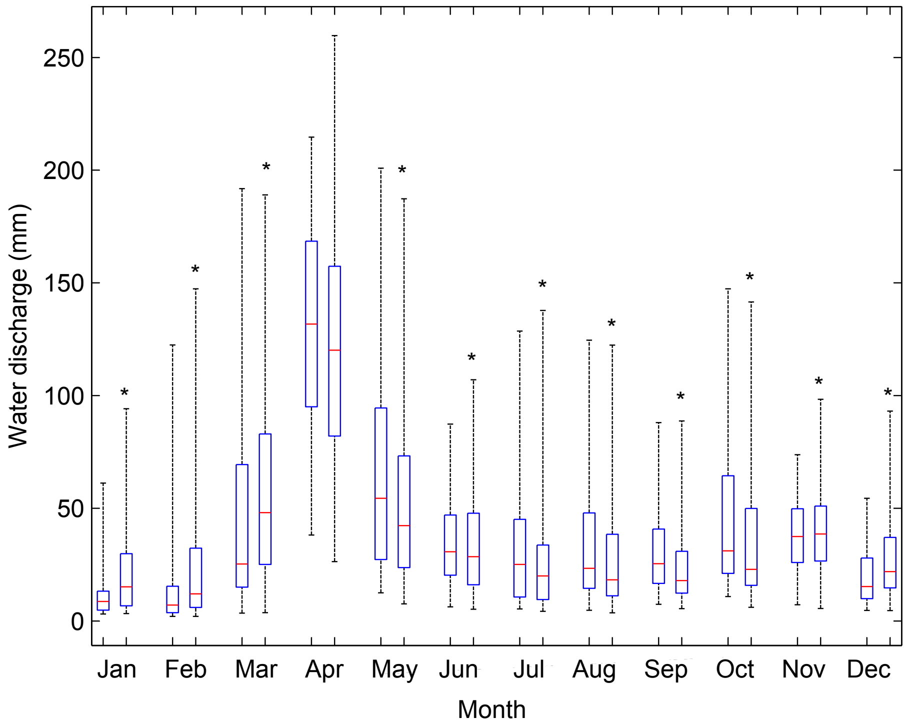

Fig. 7. Monthly water discharge as simulated for reference period (left box plots) and future period with all GCM-GES-M combinations considered as equiprobable (right box plots). Central line indicates the median value, box-plot limits indicate 1st and 3rd quartiles, and bars indicate maximum and minimum values. Stars indicate that the means are statistically different (paired t-test, $p<0.05$).

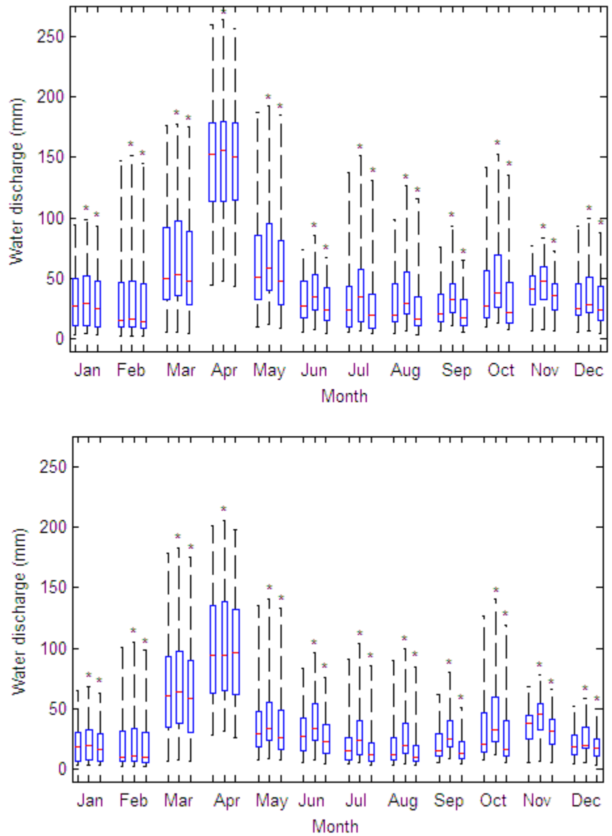

Fig. 8. Effect of land use scenarios A (middle box) and B (right box) on monthly water discharge as compared to reference land use (left box) obtained from GIBSI simulations, Delta method and two GCM-GES-M combinations (HadCM3-A2b and ECHAM4-B2). Central line indicates the median value, box-plot limits indicate 1st and 3rd quartiles, and bars indicate maximum and minimum values. Stars indicate that the means are statistically different (paired *t*-test, $p<0.05$).

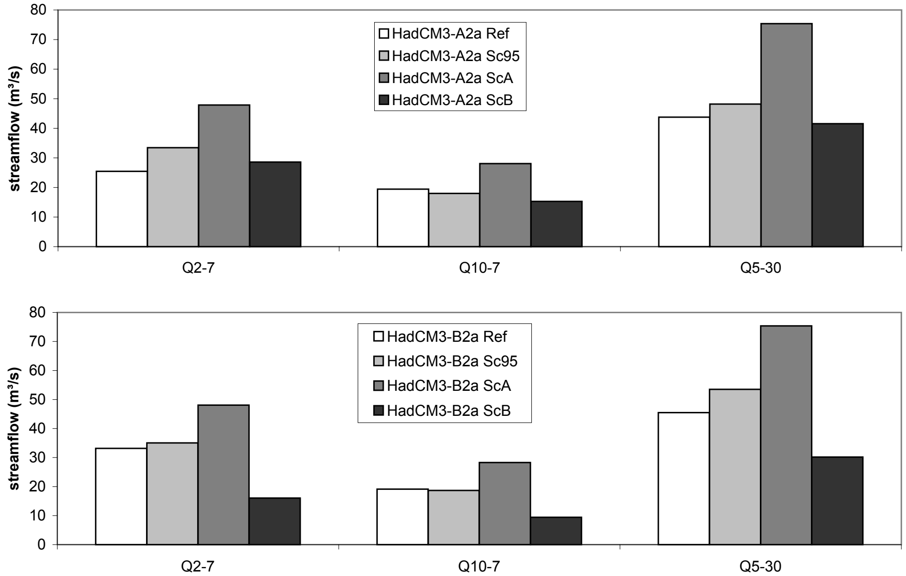

Fig. 9. Effect of CC (Sc95 vs. ref) and land use evolution scenarios (ScA and ScB vs. Sc95) on low flow statistical sequences (m^3/s) obtained with downscaling method and the two GCM-GES-M used (HadCM3-A2a and HadCM3-B2a).